ROCKET AND LABORATORY STUDIES IN AERONOMY AND ASTROPHYSICS

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I. Introduction

During this report period our effort has concentrated on analysis of data from previous rocket experiments and the preparation of two new rocket experiments 4.334 UA and 26.039 UG, both of which were successfully launched in March 1975. The preliminary scientific results as well as the new instrumentation developed for the experiments are described below. We also describe the results of the data analysis for previous rockets and the status of the laboratory and instrumentation studies.

II. Laboratory and Instrumentation Studies

Dr. Doering's laboratory work has continued in the area of electron and positive ion scattering from gases. In particular, Drs. Bregman-Reisler and Doering have clarified the optical emission spectrum of CO_2 excited by positive ion bombardment in two recent papers.

Dr. Dagdigian is studying the laser excited fluorescence of small molecules. He and Dr. Feldman are also designing a rocket-borne laser fluorescence experiment. The experimental work by Mr. Woodworth and Dr. Moos on the forbidden $2^3S_1 \rightarrow 1^1S_0$ transition in He is now complete. The result in conjunction with beam foil experiments near Z = 18 demonstrates that the theoretical calculation of the radiative transition rate for 2 electron ions which varies strongly, as Z^{10}, is valid over a wide range of ions. Hence, it may be used with confidence for the solar corona and other astrophysical EUV and soft x-ray sources.

Mr. McClintock and Professor Fastie have constructed a 0.75 m focal length echelle spectrograph of a new design using a high transmission prism for cross dispersion. Optical and spectroscopic quality studies in the visible show a spot size of 20μ over the 5 cm x 2 cm detector plane for a point image source; a resolving power better than 10^5 has been achieved. The instrument is small and light for such high resolution. The optics produce a spectrum in a 5 x 2 cm focal plane which is suitable for matching with electronic multispectral element detectors.

As part of the auroral rocket, 4.334, two new spectrometers were flown. An extreme ultraviolet (EUV) instrument using a concave grating was developed by Professor Fastie. This instrument uses many of the components of the small, light, 0.125 meter Ebert developed by this laboratory in 1973. The new instrument is also small and light (3 lb.) with digital motor control and sensitive digital photon detection. The apparatus and procedure for calibration of the EUV spectrometer were developed by Mr. Park. The second instrument was an infrared Ebert. A highly sensitive infrared detector of intrinsic germanium was developed by Mr. Beiting and flown with this instrument.

A microchannel chevron detector with resistive strip readout was flown successfully on 26.039 UG. In preparation for this, the electronic and photometric properties of microchannel plates, bare and over coated with CsI photocathodes were studied by Mr. Weiser. The studies show that the plate is a rugged, high quantum efficiency device. The spatial resolution provided by readouts such as the resistive strip make it a multi-spectral element detector, providing an enormous enhancement in sensitivity. The devices were reputed to be sensitive to dust and scratches, but with proper handling procedures this was found not to be a serious problem. Mr. Vitz developed a high efficiency prism spectrometer for the rocket experiment which uses a Vacion pump to maintain the microchannel detector and spectrometer at 10^{-6} torr until altitude.

III. Rocket Experiments

The auroral Aerobee rocket, 4.334 UA, prepared under the direction of Dr. Feldman, contained seven coordinated experiments. It was successfully launched from Churchill Research Range on 10 March 1975 into an IBC II aurora preceded by strong magnetic activity. A preliminary look at the data shows the presence of the NO γ-bands in emission, indicating an anomalously high concentration of nitric oxide in this aurora, much like the conditions seen by Dr. Zipf's mass spectrometer during our joint auroral experiment with the University of Pittsburgh in 1970 (4.309 UA). As part of this payload, two new spectrometers were flown, one to scan the extreme ultraviolet from 750 to 1250 A, and the other an infrared spectrometer with a range from 1.1 to 1.7 μ. Dr. Doering contributed the recoverable dual auroral electron spectrometer package for this experiment. Both the low energy (1-100 eV) and high energy (.1-25 keV) electron spectrometers worked well.

Another experiment prepared during the report period was a piggy-back ultraviolet spectrometer designed to look for nitric oxide fluorescence in a sunlit aurora. This instrument was included in a Nike-Apache payload built by Dr. Georg Witt of the Meteorological Institute of the University of Stockholm and was flown from Esrange, Kiruna, Sweden on 5 March 1975. The experiment was unsuccessful due to rocket failure, but we plan to repeat it during a future rocket campaign in the fall of 1976.

Aerobee 26.039 UG carried our 14 inch diameter one arc second pointing telescope to observe Saturn, α Boo and α Aur. A coordinated observation of α Boo by the Princeton Experimental Package on OAO Copernicus was performed at the same time permitting cross calibration.

The use of two insertable entrance slits allowed a large part of the Saturnian rings to be blocked for half of that observation. The radiation from 1150-1750 A was analyzed with the prism spectrometer and microchannel chevron detector discussed in section II. The very high transmission and quantum efficiency of the instrument and the use of the multispectral element detector made this the most sensitive astronomical instrument we have ever flown. The instrument and all rocket support systems worked perfectly and the package was recovered in near perfect condition. Until the flight tapes have been reduced to be compatible with our computer systems only a very preliminary analysis has been possible. α Boo and α Aur (which recently has been observed to have soft x-ray emission (R. C. Catura, L. W. Acton and H. M. Johnson, Ap. J. Letters 196, 47 (1975)) show very different spectra both in intensity and the types of lines which are excited: Saturn shows long wave radiation; the short wavelength spectral region especially Lα, will require a detailed analysis.

IV. Data Analysis

Dr. Feldman has completed analysis of the comet data obtained on our Comet Kohoutek experiment (26.023 UG, launched 4 January 1974). The most important result was the detection of atomic carbon via its resonance lines at 1657 and 1561 A. The production rate was found to be comparable to that for water vapor and implies a source of carbon other than parent hydrocarbons. We also detected the oxygen resonance line at 1304 A, but were not sensitive enough to see fluorescence from CO (a likely parent of the observed carbon) in the fourth positive bands. Since the fluorescence rate is dependent on the velocity of the comet relative to the sun, the production rates derived from the observations require detailed knowledge of the solar line shapes and intensities. A study of the resonance fluorescence factors was carried out by Dr. Feldman in collaboration with Drs. R. R. Meier, C. B. Opal and K. R. Nicolas of the Naval Research Laboratory and made use of recent solar ultraviolet spectra obtained by the Skylab program. The results of this study were presented at the IAU colloquium on comets held at GSFC in October 1974.

The Comet rocket also provided extremely fine twilight spectra from which two important new aeronomic results have been drawn. First, bands of the nitric oxide γ and δ-band systems were observed, and it was possible to show that the δ-bands resulted from the chemiluminescent reaction of atomic oxygen with atomic nitrogen. From these data the N concentration was derived. The NO γ-bands, on the other hand, are produced by resonance scattering in the sunlit region, and permitted a simultaneous determination of the NO density. The densities so determined were at a variance with recently published models and have had a serious impact on the models of odd nitrogen chemistry in the thermosphere. Incidentally, the high N density derived from this experiment is in excellent agreement with the value derived from our analysis of our December 1972 ultraviolet dayglow data (see below).

The second result is the first reported observation of the forbidden ^2P-^4S transition of O^+ at 2470 A in the undisturbed ionospheric airglow. Dr. Feldman and Dr. Takacs recently completed a model calculation in which photoionization and photoelectron impact ionization of atomic oxygen were shown to satisfactorily account for the observed emission rates and altitude dependence. The value of this observation over dayglow observations is that the emission is produced at altitudes above 300 km and is almost completely free of competing collosional quenching effects which dominate at lower altitudes.

The analysis of the dayglow spectra obtained on 13 December 1972 (13.096 UA) has been completed by Dr. Takacs. Because of the very low scattered light level from the grating used, these spectra are an order of magnitude better than previous work and permit positive identification of features as weak as 5-10 Rayleighs. As noted above the atomic nitrogen concentration was derived from the observed emission rate of atomic nitrogen transitions in the ultraviolet, and was found to be significantly higher than the predictions of recent models. Another surprising result came from a comparison of molecular oxygen densities determined from this rocket and from a University of Colorado rocket (13.094) flown two days later - an increase of a factor of 2 in the O_2 density at 120 km in a span of 48 hours. The technique used, the observation of attenuation of ultraviolet radiation in the O_2 Schumann-Runge continuum, is independent of absolute instrument calibration so that the increase cannot be accounted for by measurement uncertainty. The short time scale for this change indicates that previous claims of seasonal variation in O_2 density were probably based on an insufficient sample of data points, and that the dynamical behavior of the atmosphere near the turbopause is greater than expected.

Data from our previous auroral rocket (4.320 UA, 17 March 1972) were also analyzed. Work was completed on the secondary electron spectrum and the related optical emissions. The O_2 (0,0) atmospheric band at 7620 A was found to be the brightest of the observed emission features (it cannot be observed from the ground because of self-absorption by O_2). Work was begun on modeling the excitation of the O_2 ($b^1\Sigma_g^+$) state and our preliminary results indicate that collisional deactivation of O (^1D) by O_2 contributes about an order of magnitude more than direct electron excitation of O_2.

Drs. Moos, Mr. Giles and Mr. McKinney have completed the data analysis from Aerobee 13.047 on which Jupiter and α Boo were observed. In addition to Lyα emission, Jupiter shows reflected solar radiation from 1650-1900 Å which indicates low NH_3 and hydrocarbon abundances in the upper part of the lower atmosphere. Complex emissions were also observed from 1250 - 1550 which we have been able to show come from low energy photo or auroral electrons impacting on H_2. α Boo has a remarkably clean spectrum, consisting of Lα and OI 1304. It is very different from that of the sun and α Aur (Section III). The absence of Si IV 1400 Å and C IV 1550 Å indicates a corona with temperatures below 5×10^4°K or greater than 2.5×10^5°K; most likely the latter case is true.

Studies of the absolute brightness of the stars in the far-ultraviolet have continued. A study is under way of the far-ultraviolet spectrum (1100-3000 Å) of the unreddened manganese star α Andromedae obtained in Aerobee rocket flight 26.023. Data obtained on the Apollo 17 mission have been analyzed further and the calibration thus obtained is being intercompared with observations of hot stars by the Copernicus satellite. Further work is planned on the calibration problem, in the form of a flight in Australia in August, 1976. The experiment is described in the proposal for September 1, 1975 - August 31, 1976 submitted with this progress report.

The study of the far-ultraviolet background radiation by Dr. Henry is continuing using rocket photometer measurements, Apollo 17 data and star-catalog integration. At the very least an upper limit on any possible cosmological background radiation has been set, which is about a factor 5 below previous upper limits. It also appears that a marginal signal was actually obtained on Apollo 17, and the analysis of the data is continuing in the hope of determining whether the radiation is galactic far-ultraviolet starlight scattering off interstellar grains at high galactic latitude, or is extragalactic.

A paper will be published in a few months. To pursue the question further experimentally, a package is being prepared which will fly in February 1976 as an add-on experiment on a West German Aries rocket to be flown from White Sands Missile Range.

Publications

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Auroral Electrons and the Optical Emissions of Nitrogen, accepted for publication in J. Geophys. Res. (P. D. Feldman and J. P. Doering)

Far Ultraviolet Excitation Processes in Comets, to be published in Proc. IAU Colloquium #25. (P. D. Feldman, C. B. Opal, R. R. Meier and K. R. Nicolas)

Low-Resolution Ultraviolet Spectroscopy of Several Hot Stars Observed from Apollo 17, to be published by Astrophys. J. (R. C. Henry, A. Weinstein, P. D. Feldman, W. G. Fastie and H. W. Moos)

Spectroradiometric Calibration Techniques in the Far Ultraviolet: A Stable Emission Source for the Lyman Bands of Molecular Hydrogen, submitted to Appl. Opt. (W. G. Fastie and D. E. Kerr)

Twilight Observations of the Forbidden $O^+(^2P-^4S)$ Transition at 2470 A, submitted to J. Geophys. Res. (P. D. Feldman and P. Z. Takacs)

Papers Presented

P. D. Feldman and P. Z. Takacs, "Fluorescence of Molecular Hydrogen in the Mesosphere," AGU, Washington, D. C., April 1974.

P. D. Feldman, "Rocket Ultraviolet Spectrophotometry of Comet Kohoutek (1973f)," invited paper, AGU, Washington, D. C., April 1974.

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